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PRELIMINARY BURN AND IMPACT TESTS OF HYBRID  
POLYMERIC COMPOSITES

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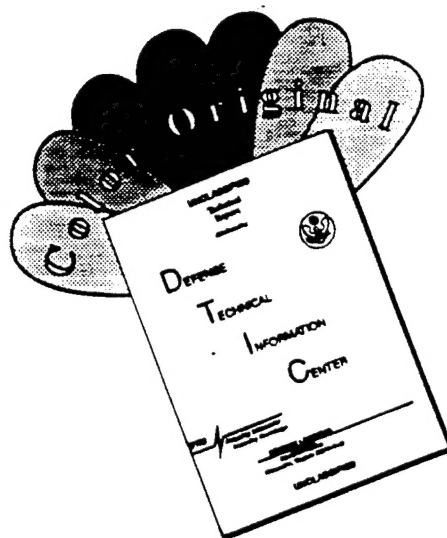
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By

Stephen S. Tompkins and William D. Brewer

ABSTRACT

Recent studies have shown that free graphite fibers released into the environment from resin matrix composite components, as a result of fire and/or explosion, pose a potential hazard to electrical equipment. An approach to prevent the fibers from becoming airborne is to use hybrid composite materials which retain the fibers at the burn site. Test results are presented for three hybrid composites that were exposed to a simulation of an aircraft fire and explosion. The hybrid systems consisted of 16 plies of graphite-epoxy with two plies of Kevlar-, S-glass-, or boron-epoxy on each face. Two different test environments were used. In one environment, specimens were heated by convection only, and then impacted by a falling mass. In the other environment, specimens were heated by convection and by radiation, but were not impacted. The convective heat flux was about  $100\text{--}120 \text{ kW/m}^2$  in both environments and the radiative flux was about  $110 \text{ kW/m}^2$ .

A large quantity of graphite fibers was airborne upon impact of graphite epoxy and the Kevlar-graphite hybrid specimens which had been subjected to the burn tests. Significantly fewer airborne graphite fibers resulted from the impact of burned boron- and glass-graphite hybrid specimens. The relative performance of each hybrid was the same in the two environments.

## INTRODUCTION

Structural components of graphite-reinforced epoxy resin are presently being used in selected areas of aircraft and space structures. The experience gained from the research and development programs and production of composite structures indicates that graphite fiber composites can have better specific properties than metals and hence can reduce weight and provide significant benefits in cost and performance. However, recent studies have shown that these benefits may not be realized without some risk. In particular, the graphite fibers used in composite materials are very good electrical conductors and the release of free fibers into the environment, by a fire and explosion for example, can present a hazard to electrical equipment (refs. 1 and 2). The physical characteristics of the fibers (small diameter, short length, low density) are such that normal atmospheric winds or currents can transport the fibers over relatively long distances. Graphite fibers which

settle on or across electrical contacts or circuits can cause: (1) resistive loading; (2) temporary shorts; or (3) electrical arcing.

Two general approaches can be taken to minimize or eliminate the graphite fiber hazard. In one approach, the graphite fibers can be treated or coated to significantly reduce the electrical conductivity, increase the oxidation rate, or increase the density, making the fibers less buoyant. The second approach is to prevent the fibers from becoming airborne by using containment methods to retain the fibers at the release site. A simple containment scheme involves the use of hybrid composites. The hybrid may contain the fibers by causing them to clump or by providing tough outer plies over the graphite filled laminate. The hybrid approach appears to be the most promising for providing a reliable solution in a short time with minimum perturbation to the current graphite-fiber composites technology.

Published data on hybrid composites designed to prevent graphite fibers release due to burn and impact, as well as to provide structural integrity in the service environment, are very limited. The purpose of this paper is to present results from preliminary burn and impact tests of several hybrid composites. The objective of the tests was to qualitatively determine how well several hybrid systems retained the fibers in a fire and impact environment.

## MATERIALS AND HYBRID SPECIMENS

The hybrid composite materials used in these exposure tests were combinations of graphite and glass, boron or aramid fibers in an epoxy resin. All of the materials were obtained in prepreg tape about 30 cm wide from the vendor. The specific prepreg tapes used were:

Thornel 300 graphite fibers with Fiberite 934 epoxy resin; tape fabricated by Fiberite Corporation

S-glass fiber with Fiberite 934 epoxy resin; tape fabricated by Fiberite Corporation

Kevlar 49 aramid fibers with Fiberite 934 epoxy resin, tape fabricated by Fiberite Corporation

Boron fibers with Fiberite 934 epoxy resin, tape fabricated by Composite Technology Incorporated.

(Identification of commercial products in this report is to adequately describe the materials and does not constitute official endorsement, expressed or implied, of such products, or of the fabricator, by the National Aeronautics and Space Administration.)

The hybrid composites specimens consisted of two plies of S-glass, Kevlar-, or Boron-epoxy on each side of 16 plies of graphite-epoxy. Specimens of 20 plies of graphite-epoxy were used as control samples. Each specimen was about 76 mm square

and 3 mm thick. All of the specimens were fabricated at NASA-LaRC from prepreg type purchased from vendors.

Seven pairs of specimens were fabricated: one pair of control specimens of graphite-epoxy and two pairs of specimens of each of the three hybrid systems. One pair of specimens of each hybrid had the fibers in the two top and bottom plies oriented  $90^{\circ}$  to the graphite fibers in the 16 interior plies, whereas, all fibers in the second pair of hybrid specimens were unidirectional. All but two of the specimens, one each of the boron- and Kevlar-graphite cross-ply hybrids, fabricated for this study were tested.

#### TEST PROCEDURES AND CONDITIONS

Tests were conducted at both the NASA Langley Research Center (NASA-LaRC) and at AVCO-Specialty Materials, Lowell, Massachusetts. The test apparatus used for 9 tests at the NASA-LaRC tests is shown in figure 1. A specimen was placed in the burn chamber in a horizontal position and supported along two edges. The graphite fiber direction was from one support to the other. A propane torch was directed onto the top surface of the specimen with the flame impinging on the surface. The air-fuel mixture was adjusted to give the maximum flame temperature. The surface temperature during these tests was in the range of 1175-1320 K as measured with an optical pyrometer. This corresponds to an equilibrium radiation flux

of about  $120 \text{ kW/m}^2$ . After a 15-minute burn period, the torch was turned off, an exhaust fan was turned on, and a 0.5-kg steel mass was dropped onto the specimens with an impact energy of about 5J. The impacting surface was spherical with a 6.4 mm radius. The air flow through the apparatus was about 5 m/s. A stainless steel filter with 100  $\mu\text{m}$  openings was located in front of the exhaust fan and collected the released fibers and debris. About 3 minutes after each impact, the material collected on the filter was removed with adhesive-backed paper.

Three tests were conducted at AVCO in their Model 25 Fire Simulation Facility which has a resistance heated hood for radiative heating and burns natural gas for convective heating (ref. 3). For these tests, the hood temperature was maintained at about 1280 K which corresponds to an equilibrium radiation flux of about  $110 \text{ kW/m}^2$  and the convective heating rate was estimated at about  $100 \text{ kW/m}^2$ . Each specimen was burned for 10 minutes. The specimens were not impacted and no attempt was made to collect fibers released during the burn tests.

## RESULTS AND DISCUSSION

### Tests at NASA-LaRC

Only a very few fibers were released during the 15-minute burn of any of the specimens. Some soot was collected during the burn phase of each test. Heating the specimens with the

propane torch resulted in a non-uniform temperature distribution across each specimen, with maximum temperatures reaching 1175-1320K. A surface temperature of about 1370K is expected for composite materials in aircraft fires. The non-uniform temperature distribution over the specimen probably caused the specimen buckling observed in each test. The epoxy matrix material in all specimens was charred through the thickness, but except for some front surface oxidation in the hotter regions, the char remained intact until the impact. The overall performance of each hybrid appeared independent of the fiber orientation in these tests, therefore, the data from only one specimen of each hybrid system and the control are reported. The data from the NASA-LaRC tests are shown in figures 2-5 and consist of a photograph of each specimen after impact, and two magnified views of the debris collected on the filter after impact.

Graphite-epoxy control specimen.- A graphite-epoxy control specimen is shown in figure 2. The impact broke the specimen into many small and large pieces, figure 2(a). The filter was uniformly covered by fibers and some soot, figure 2(b). Although most of the debris on the filter consisted of single fibers of various lengths, a few fiber clumps are present, figures 2(b) and 2(c).

Kevlar-graphite hybrid.- The behavior of the Kevlar-graphite hybrid, figure 3, was similar to that of the

graphite-epoxy control (fig. 2). The top layers of Kevlar were completely burned away prior to the impact, leaving the charred graphite-epoxy unprotected. The impact resulted in many small and large pieces, figure 3(a). The debris from the filter contained many small individual fibers and fiber clumps. More soot appeared on the filter than in the control specimen tests. The additional soot was probably due to the burned Kevlar.

Boron-graphite hybrid.- During the burn period, the top two boron-epoxy plies delaminated and curled. Beads of  $B_2O_3$  formed on some of the boron fiber ends. Although the boron-graphite hybrid delaminated and broke into several large and many small pieces on impact, figure 4(a), only a few fibers collected on the filter, figures 4(b) and (c). If the boron-epoxy lamina could be held in place, perhaps by stitching, the boron-hybrid may be a promising system for containing the graphite fibers.

S-glass-graphite hybrid.- In these tests, the surface temperature was not high enough to soften the S-glass and the top two plies of the S-glass graphite hybrid peeled off and curled during the burn period, figure 5(a). However, the two glass plies did not separate from each other. This hybrid appeared to absorb the impact much better than the other material systems tested. Because the specimen stayed generally intact, figure 5(a), only in a few fibers collected on the filter, figure 5(b). Both glass and graphite fibers collected on the filter, figure 5(c).



Photographs of the debris collected on the filter after impact of each of the material systems are compared in figure 6. The debris from the control and the Kevlar-graphite hybrid specimens were similar and contained many fibers. Because the Kevlar burned away, it had little effect on the number of fibers released upon impact. The debris from both the boron-graphite and S-glass-graphite hybrids contained significantly fewer fibers than that from the other two specimens. Therefore, further testing of boron and S-glass is warranted to fully evaluate their potential for controlling graphite fiber release in fires.

#### Tests at AVCO

Photographs of the three hybrid specimens, S-glass-graphite, boron-graphite and Kevlar-graphite, burned in the AVCO Model 25 Fire Simulation Facility are shown in figure 7. The specimens appeared to have been more uniformly heated than those tested at NASA-LaRC, probably because of the radiant heating which was not present in the NASA-LaRC tests. However, the upstream edge of the specimens (the right edge as shown in figure 7) suffered the most damage. As in the NASA-LaRC tests, the specimens were charred throughout. The surfaces of the S-glass-graphite specimen remained smooth after the burn period, figure 7(a). The specimen remained intact with apparently no fibers released even though the specimen buckled noticeably. The surface temperature was high enough to cause

the glass to soften and the glass fibers to stick together. The softening and some melting of the glass fibers can be seen more clearly in figure 8, which shows three enlarged views of the glass surface after testing.

The surface of the boron graphite hybrid became very rough during the burn period, figure 7(b). The boron fibers in the top two plies were exposed to the hot gas and many were completely or partially oxidized. Beads of  $B_2O_3$  were seen on many of the boron fibers. The Kevlar plies were burned off the top of the Kevlar-graphite hybrid, as in the NASA-LaRC tests, leaving the exposed graphite-epoxy plies.

The differences between effects of the NASA-LaRC and AVCO test environments are indicated by a comparison of two S-glass-graphite hybrid specimens tested for 10 minutes in these environments, figure 9. The AVCO environment resulted in a more uniformly heated surface and higher surface temperatures. In the AVCO tests, the glass softened and stuck together, whereas very little softening of the glass was observed in the NASA-LaRC tests. Also, the marking ink used during fabrication is still visible on the surface of the NASA-LaRC-tested specimen but it was burned off the AVCO-tested specimen. Although not explicitly shown in these tests, the composition of the hot gas stream may be as important as temperature because both the epoxy resin system and the fibers are subject to oxidation. The composition of the gas stream was not determined in either the AVCO or the LaRC tests.

## Considerations for Future Testing

The present tests provide a qualitative assessment of the relative performance of some hybrid composite systems in burn and impact tests. However, in future tests more consideration must be given to obtaining more quantitative data on test conditions as well as on material response. The fact that, in the present program, the materials behaved differently in the two facilities emphasized the need to define a realistic test environment and to standardize screening test procedures. The significant test parameters (e.g. radiative and convective heating rates, oxygen concentration, surface temperatures, flow conditions or others) must be defined and their ranges of values specified. Material parameters such as weight of fibers released, number of fibers released, fiber length distribution and perhaps some "clumping" parameters are very important but may not be readily measurable. Studies must be undertaken to determine the type of data that will yield the most information and the best methods of data collection.

Anything that is done to hybridize a composite for improved fiber release characteristics must, of course, have acceptable impact on fabricability, structural properties, and cost. These factors must be considered before final judgement can be made on the applicability of a particular hybrid system.

## CONCLUDING REMARKS

Three hybrid graphite composite systems were exposed to a simulated fire and explosion to qualitatively evaluate how well each system inhibits fibers from becoming airborne. Specimens of the hybrid systems, consisting of two plies of Kevlar-, S-glass- or boron-epoxy on both faces of 16-ply graphite-epoxy composites, were subjected to two environments with and without subsequent impact. In one environment, specimens were heated by convection only, provided by a propane torch, and then impacted by a falling mass. In the other environment, specimens were heated by convection, provided by burning natural gas, and by radiation, provided by a resistance heated hood, but were not impacted. The convective heat flux was about  $100\text{--}120 \text{ kW/m}^2$  in both environments and the radiative flux was about  $110 \text{ kW/m}^2$ .

The relative performance of the hybrid systems during the burning period was the same in each environment. However, the glass and boron hybrids performed differently in the different environments. The combined convective and radiative heating produced surface temperatures high enough to cause the glass fibers to soften and stick together. Heating only with convection at  $110\text{--}120 \text{ kW/m}^2$  was not sufficient to soften the glass in these tests. The debris collected after impact of the boron- and S-glass-graphite hybrids contained significantly fewer graphite fibers than did Kevlar plies burned away leaving

the unprotected graphite-epoxy.

Therefore, the boron- and S-glass-graphite hybrids are recommended for further testing to evaluate their impact on fabrication, structural properties and cost. These factors must be considered before a final hybrid system is selected.

The fact that the material systems behaved differently in the different environments emphasizes the need to define a realistic test environments and to standardize test procedures for screening tests. The significant test parameters must be defined and their ranges of values specified. Work is required to determine the type of data that will yield the most information and the best methods of data collection.

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3. Belason, B., Castle, G., Crowley, D. and D'Avanzo, L.: A Fire Simulation Facility for Materials Response Testing. Fire Technology, vol. 6, no. 2, May 1970, pp. 179-188.

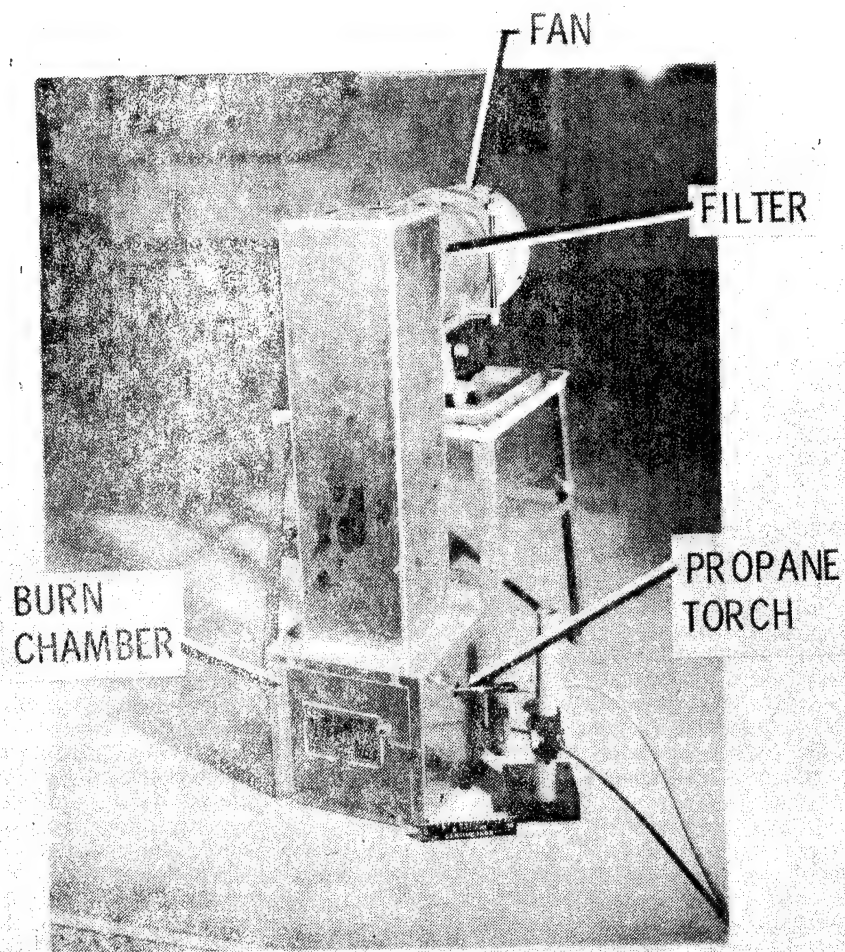


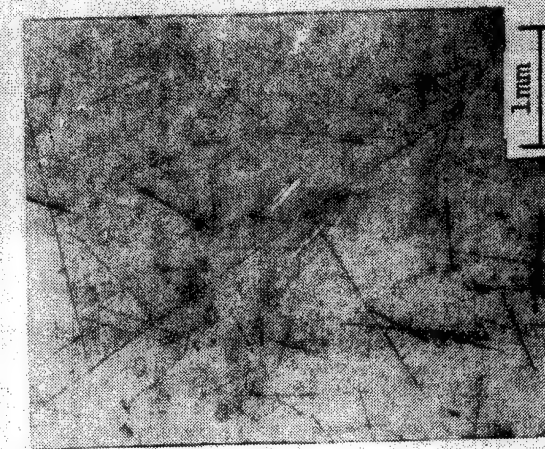
Figure 1.- Burn and impact test apparatus at NASA Langley Research Center.

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(a) AFTER 15 MINUTE  
BURN AND IMPACT



(b) DEBRIS FROM FILTER  
AFTER IMPACT



(c) FIBERS FROM FILTER  
AFTER IMPACT

Figure 2.- Graphite-epoxy after burn and impact test at NASA  
LaRC



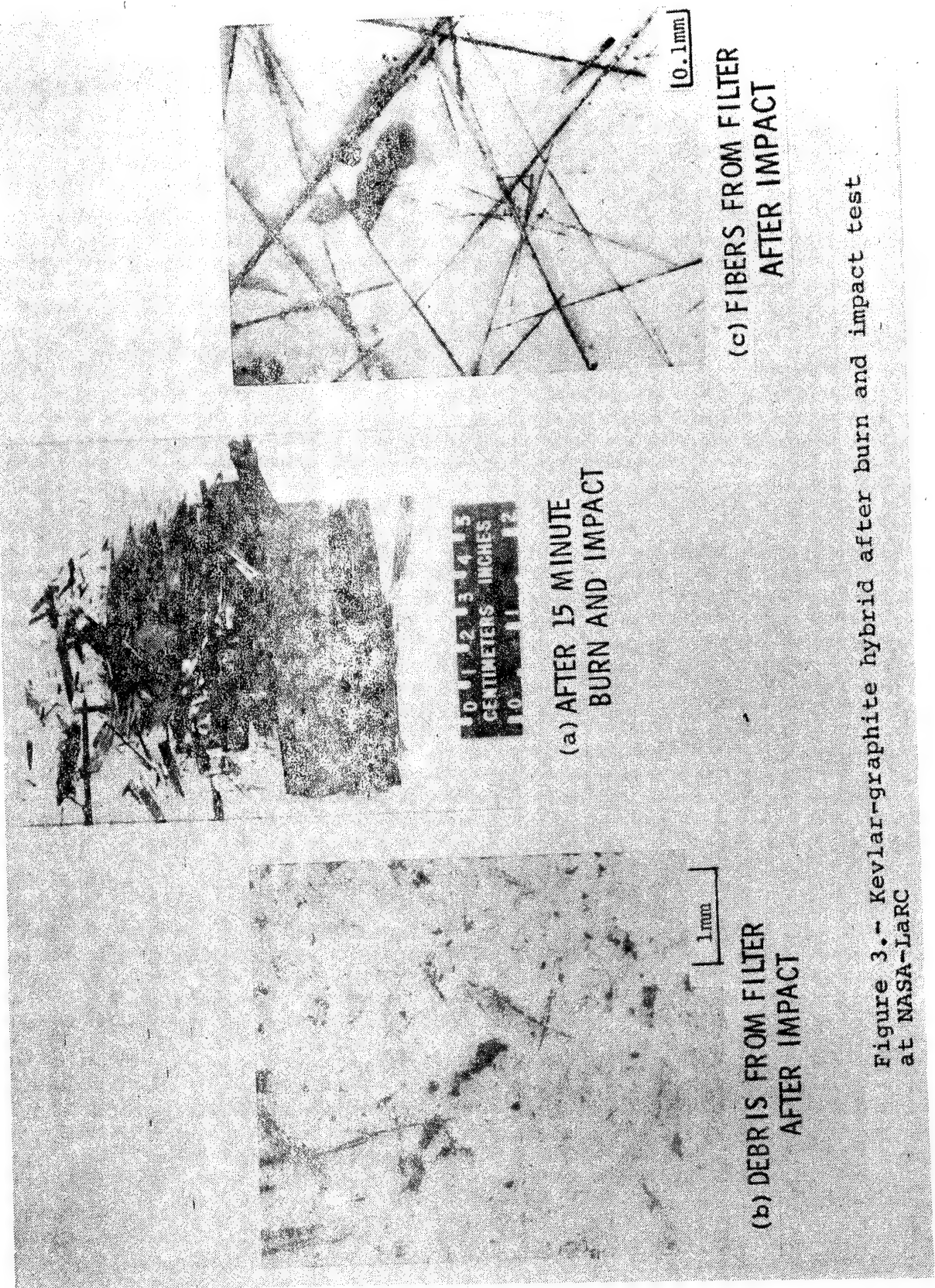


Figure 3.- Kevlar-graphite hybrid after burn and impact test  
at NASA-LaRC



(a) AFTER 15 MINUTE BURN  
AND IMPACT



(b) DEBRIS FROM FILTER  
AFTER IMPACT



(c) FIBERS FROM FILTER  
AFTER IMPACT

Figure 4.- Boron-Graphite hybrid after burn and impact test at  
NASA-LaRC



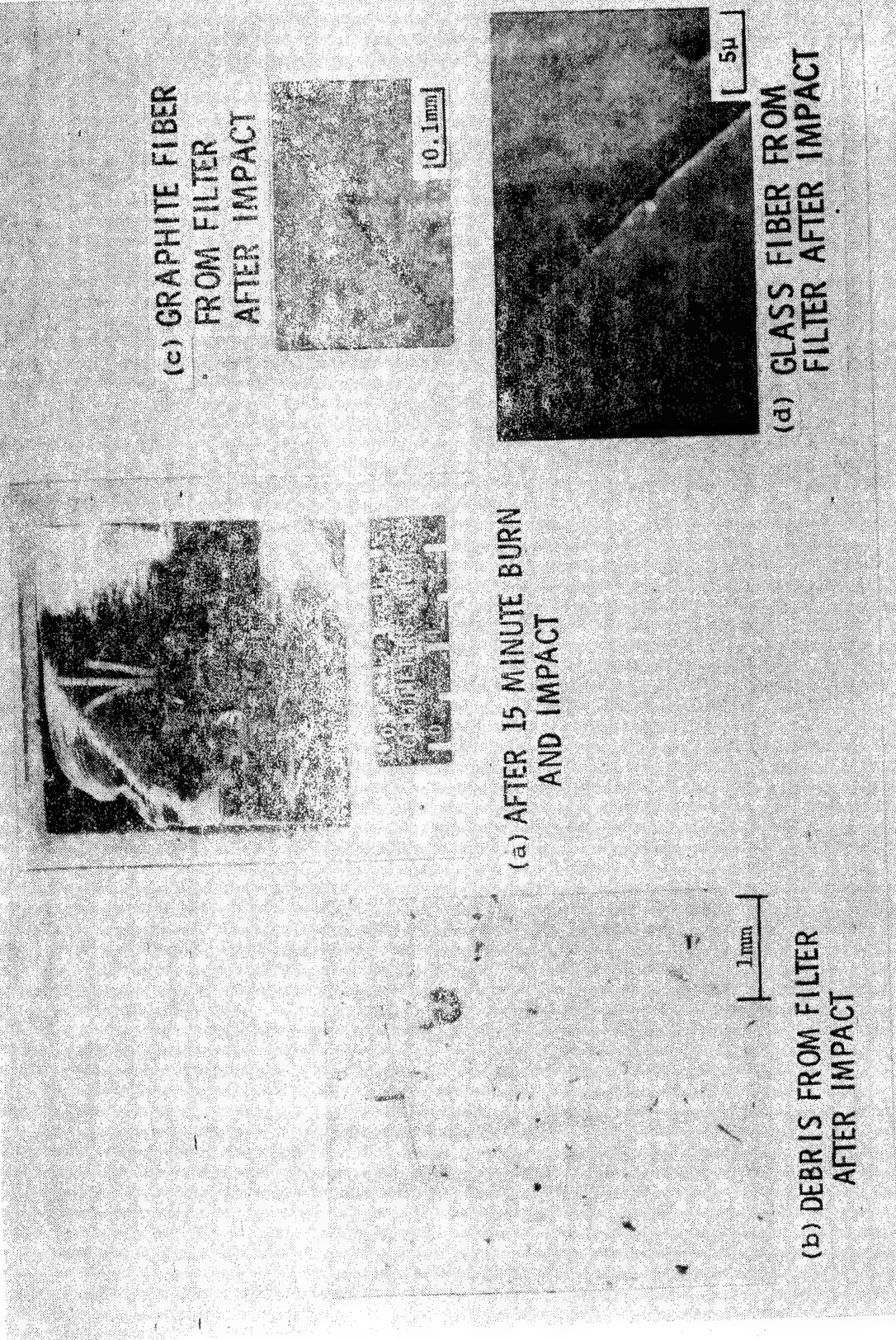
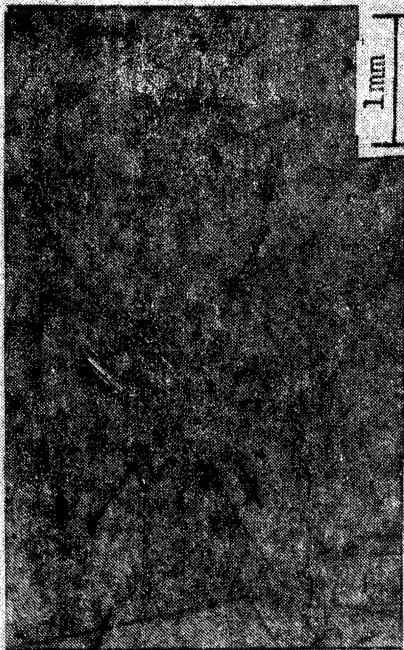
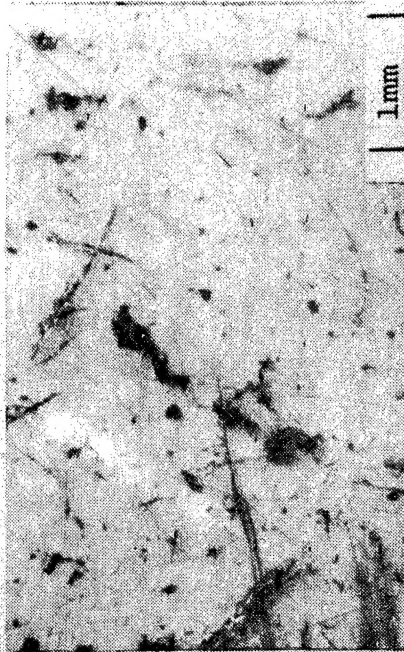


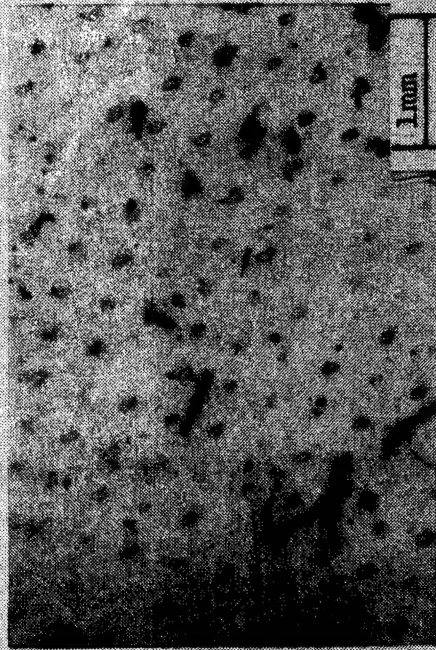
Figure 5.- S-glass-graphite hybrid after burn and impact test  
at NASA-LaRC



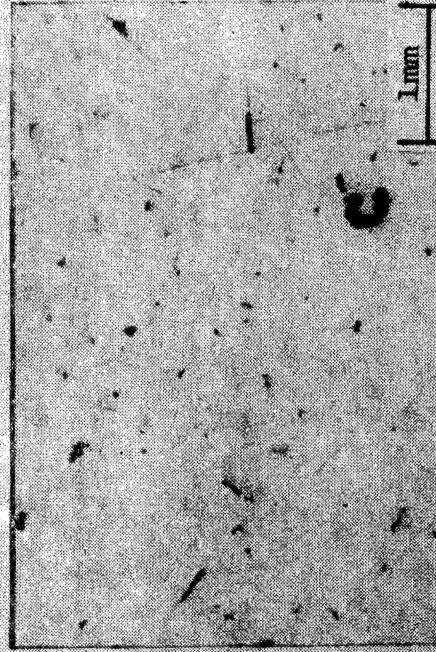
(a) GRAPHITE



(b) KEVLAR/GRAPHITE HYBRID



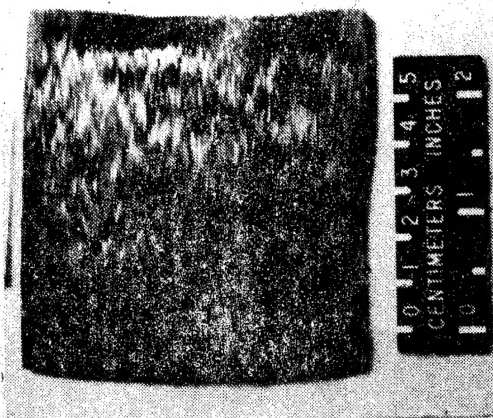
(c) BORON/GRAPHITE HYBRID



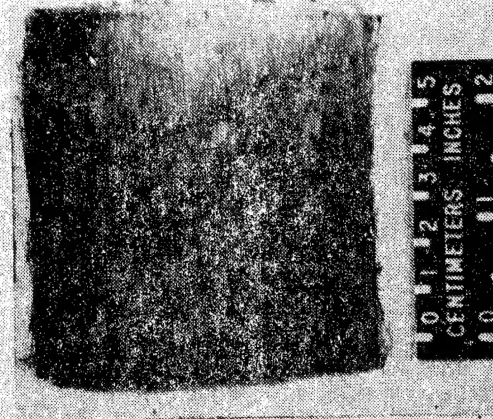
(d) S-GLASS/GRAPHITE HYBRID

Figure 6.- Comparison of debris collected on the filter after each of four 15-minute burn and impact tests at NASA-LaRC.

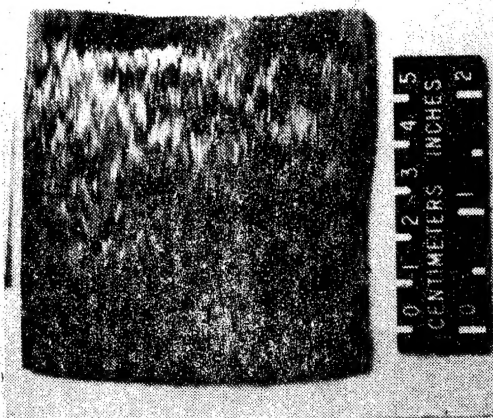




(a) S-GLASS/GRAPHITE HYBRID



(b) BORON/GRAPHITE HYBRID



(c) KEVLAR/GRAPHITE HYBRID

Figure 7.- Hybrids burned at AVCO for 10 minutes with radiative  
(110 kW/m<sup>2</sup>) and convective (100 kW/m<sup>2</sup>) heating in air.

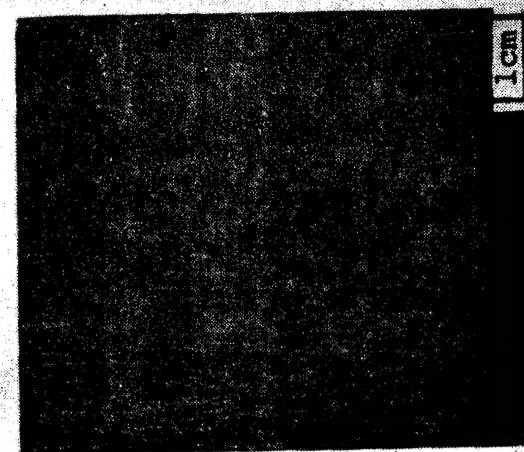
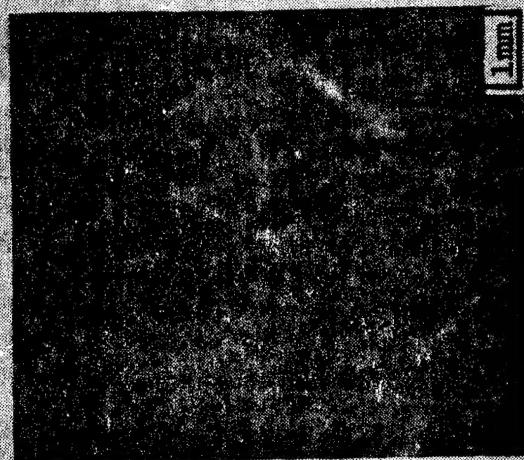
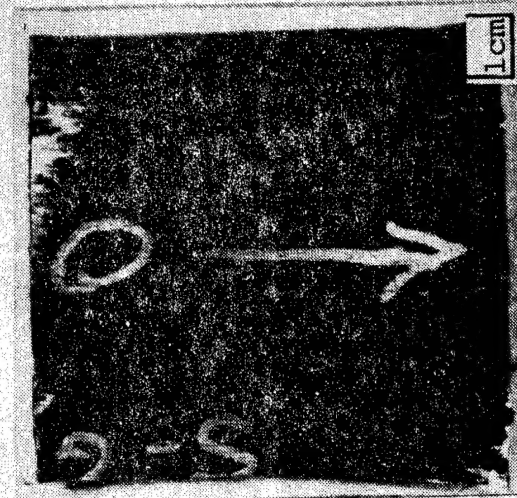
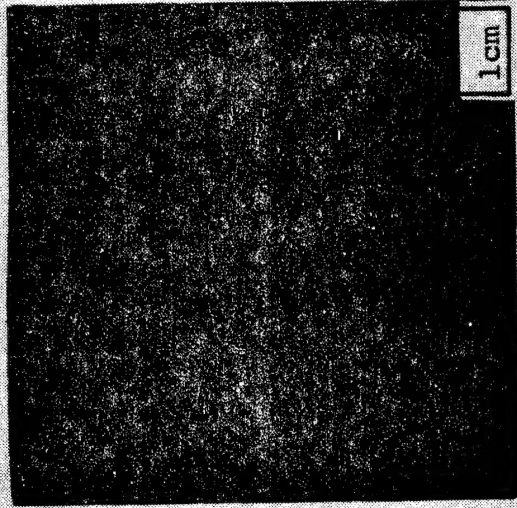


Figure 8.- S-glass/graphite hybrid burned at AVCO for 10 minutes with radiative ( $110 \text{ kW/m}^2$ ) and convective ( $100 \text{ kW/m}^2$ ) heating in air.

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(a) NASA-LRC  
PROPANE TORCH  
CONVECTION ONLY



(b) AVCO  
RADIATION AND  
NATURAL GAS  
CONVECTION

Figure 9.- S-Glass/graphite hybrid after 10-minute burn test.